Aquifer Paramater Estimation

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Aquifer Parameters

- In order to assess groundwater potential in any area and to evaluate the impact of pumpage on groundwater regime, it is essential to know the aquifer parameters. These are Storage Coefficient (S) and Transmissivity (T).

Storage Coefficient (S) is the property of aquifer to store water in the soil/rock pores. The storage coefficient or storativity is defined as the volume of water released from storage per unit area of the aquifer per unit decline in hydraulic head.

Transmissivity (T) is the property of aquifer to transmit water. Transmissivity is defined as the rate at which water is transmitted through unit width and full saturated thickness of the aquifer under a unit hydraulic gradient.

Groundwater Assessment

Estimation of subsurface inflow/outflow –

$$I_g \ or \ O_g = \sum^{L} T \ I \ \Delta L$$

Change in groundwater storage –

$$\Delta S = \sum \Delta h \ A \ S$$

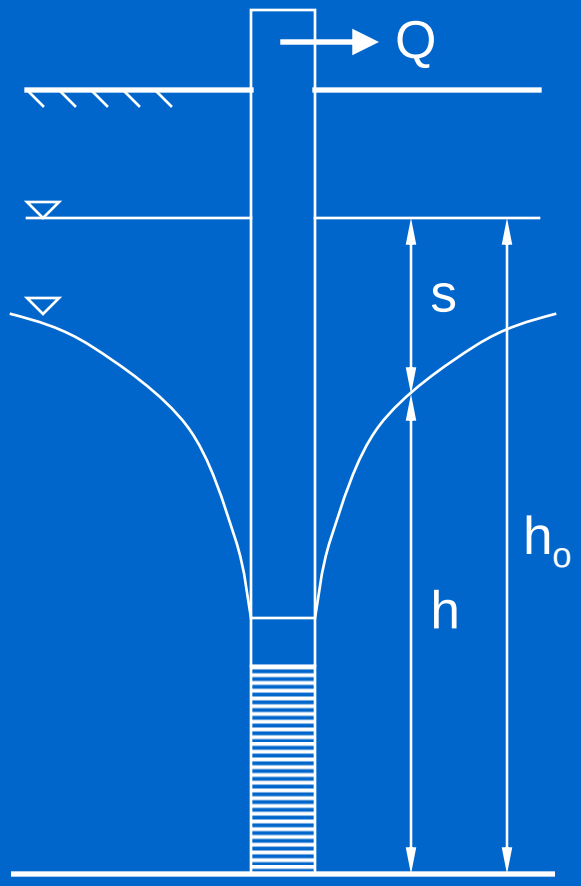
Groundwater Modelling

- Spatial variation of S and T required

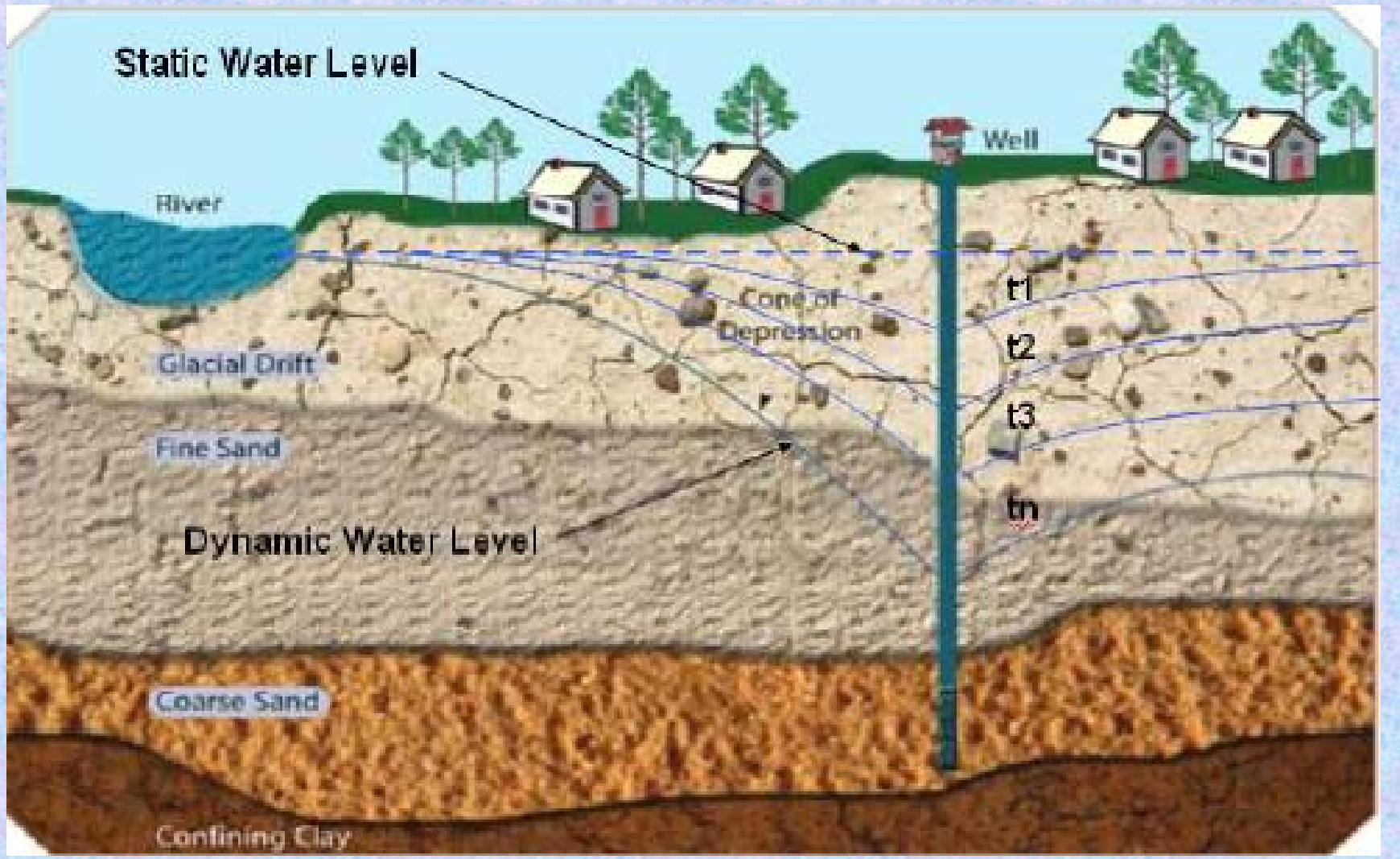
Pumping Test

- Pumping Test is the examination of aquifer response, under controlled conditions, to the abstraction of water. Pumping test can be well test (determine well yield) or aquifer test (determine aquifer parameters).
- The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response by monitoring drawdown in observation well(s) as a function of time.
- These measurements are then incorporated into an appropriate well-flow equation to calculate the hydraulic parameters (S & T) of the aquifer.

Pumping Well Terminology

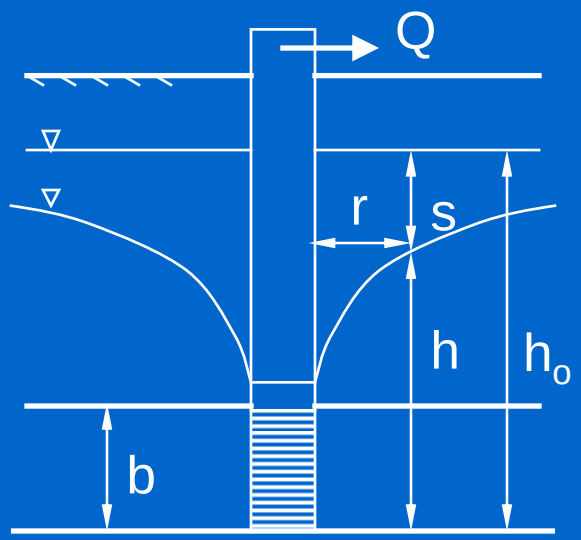


- **Static Water Level** [SWL] (h_o) is the equilibrium water level before pumping commences
- **Pumping Water Level** [PWL] (h) is the water level during pumping
- **Drawdown** ($s = h_o - h$) is the difference between SWL and PWL
- **Well Yield** (Q) is the volume of water pumped per unit time
- **Specific Capacity** (Q/s) is the yield per unit drawdown



Pumping tests allow estimation of transmission and storage characteristics of aquifers (T & S).

Steady Radial Confined Flow



- **Assumptions**
 Isotropic, homogeneous, infinite aquifer, 2-D radial flow
- **Initial Conditions**
 $h(r,0) = h_o$ for all r
- **Boundary Conditions**
 $h(R,t) = h_o$ for all t

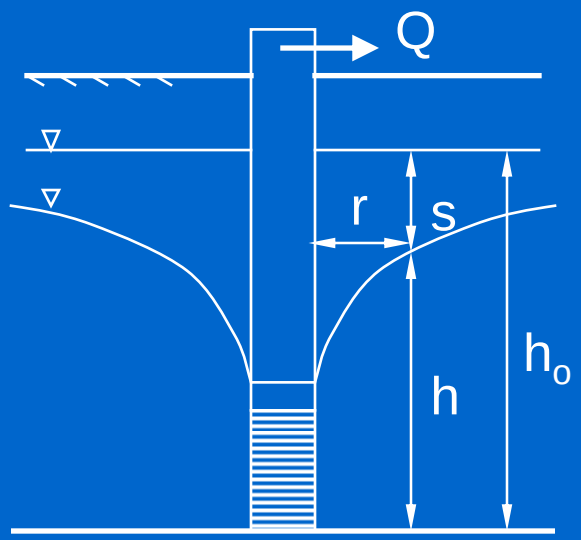
- Darcy's Law $Q = -2\pi rbK\partial h/\partial r$
- Rearranging $\partial h = \frac{-Q}{2\pi Kb}\frac{\partial r}{r}$
- Integrating $h = \frac{-Q}{2\pi Kb}\ln(r) + c$
- BC specifies $h = h_o$ at $r = R$

- Using BC $h_o = \frac{-Q}{2\pi Kb}\ln(R) + c$
- Eliminating constant (c) gives

$$s = h_o - h = \frac{Q}{2\pi Kb}\ln(r/R)$$

This is the Thiem Equation

Steady Unconfined Radial Flow



- **Assumptions**
 Isotropic, homogeneous, infinite aquifer, 2-D radial flow
- **Initial Conditions**
 $h(r,0) = h_o$ for all r
- **Boundary Conditions**
 $h(R,t) = h_o$ for all t

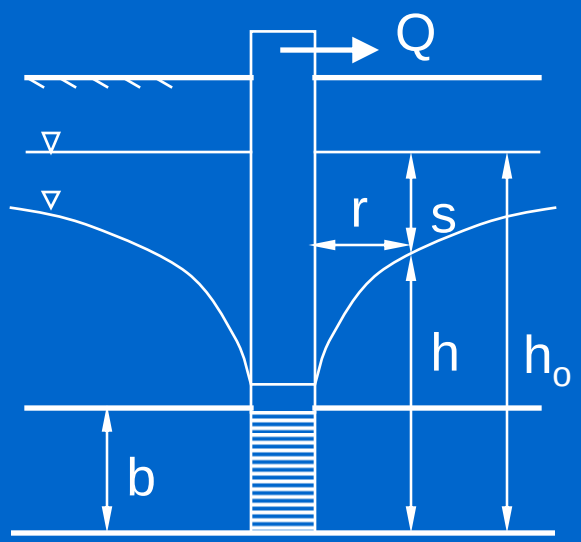
- Darcy's Law $Q = -2\pi rhK\partial h/\partial r$
- Rearranging $h\partial h = \frac{-Q}{2\pi K}\frac{\partial r}{r}$
- Integrating $\frac{h^2}{2} = \frac{-Q}{2\pi K}\ln(r) + c$
- BC specifies $h = h_o$ at $r = R$

- Using BC $h_o^2 = \frac{-Q}{\pi K}\ln(R) + c$
- Eliminating constant (c) gives

$$h_o^2 - h^2 = \frac{Q}{\pi K}\ln(r/R)$$

This is the Thiem Equation

Unsteady Radial Confined Flow



- **Assumptions**

 Isotropic, homogeneous, infinite aquifer, 2-D radial flow
- **Initial Conditions**

 $h(r,0) = h_o$ for all r
- **Boundary Conditions**

 $h(\infty,t) = h_o$ for all t

- PDE $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial h}{\partial r}\right) = \frac{S}{T}\frac{\partial h}{\partial t}$
- Solution is more complex than steady-state
- Change the dependent variable by letting $u = \frac{r^2 S}{4Tt}$

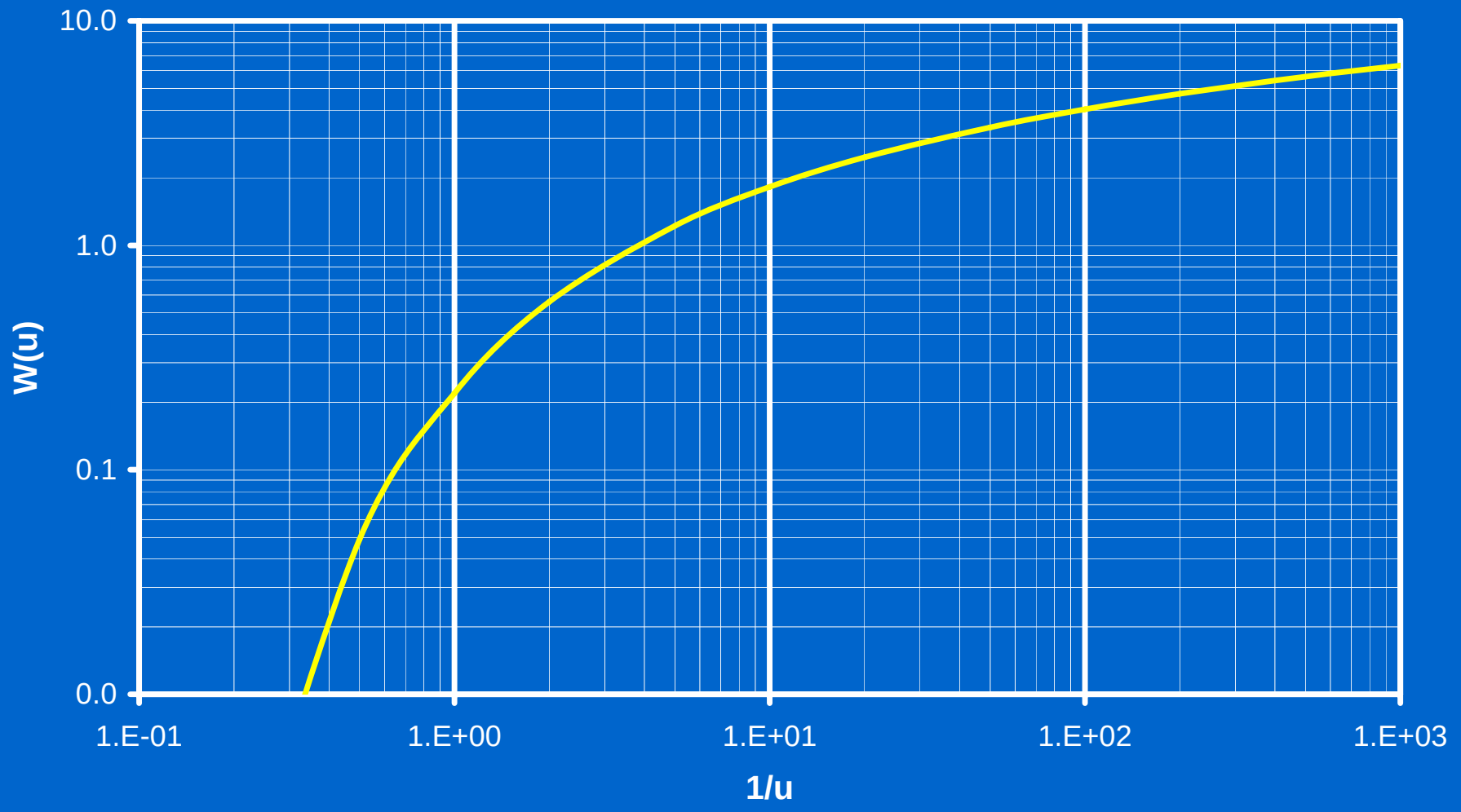
- The ultimate solution is:

$$h_o - h = \frac{Q}{4\pi T}\int_u^\infty \frac{\exp(-u)}{u}\,du$$

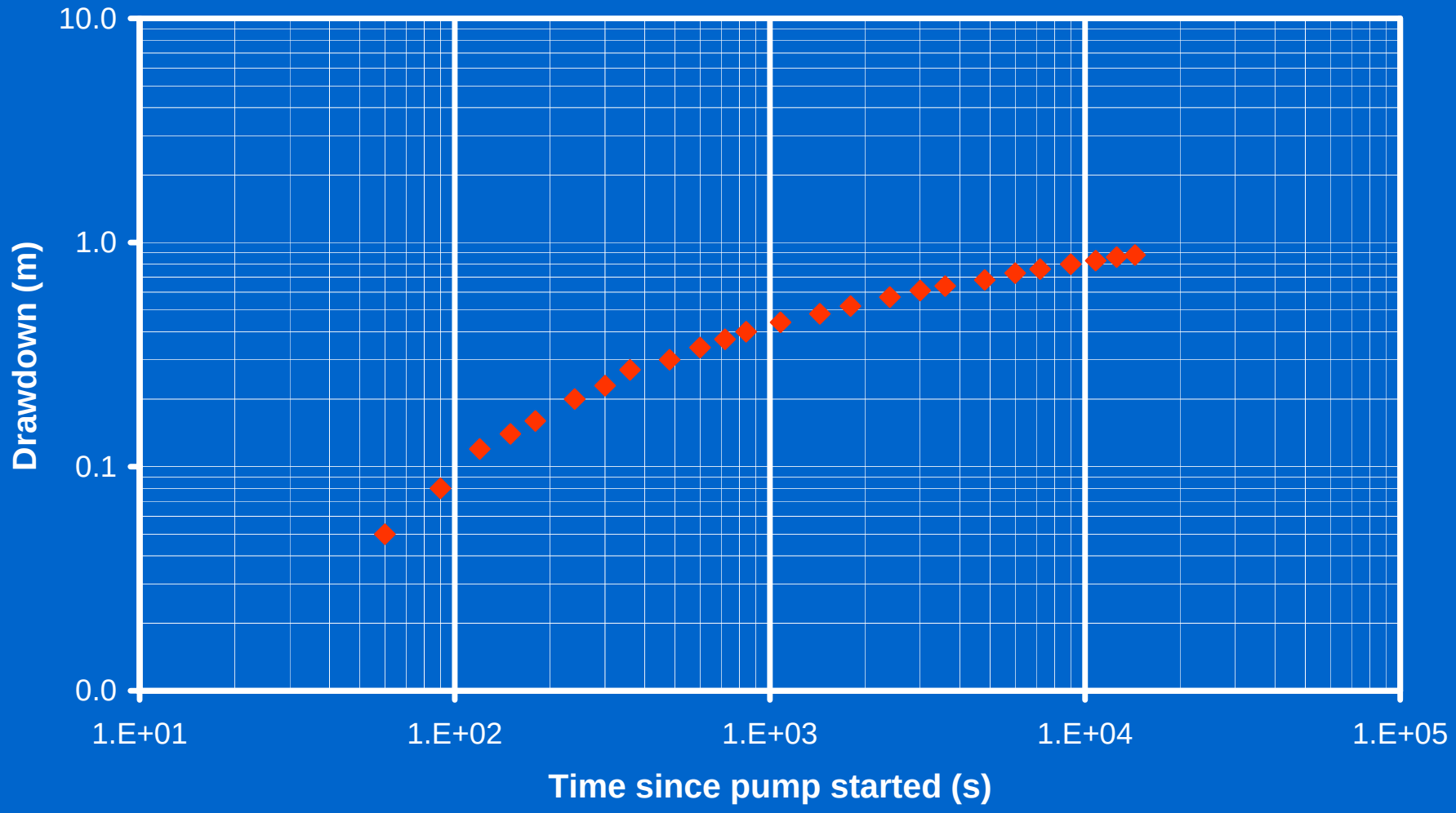
where the integral is called the exponential integral written as the well function W(u)

This is the Theis Equation

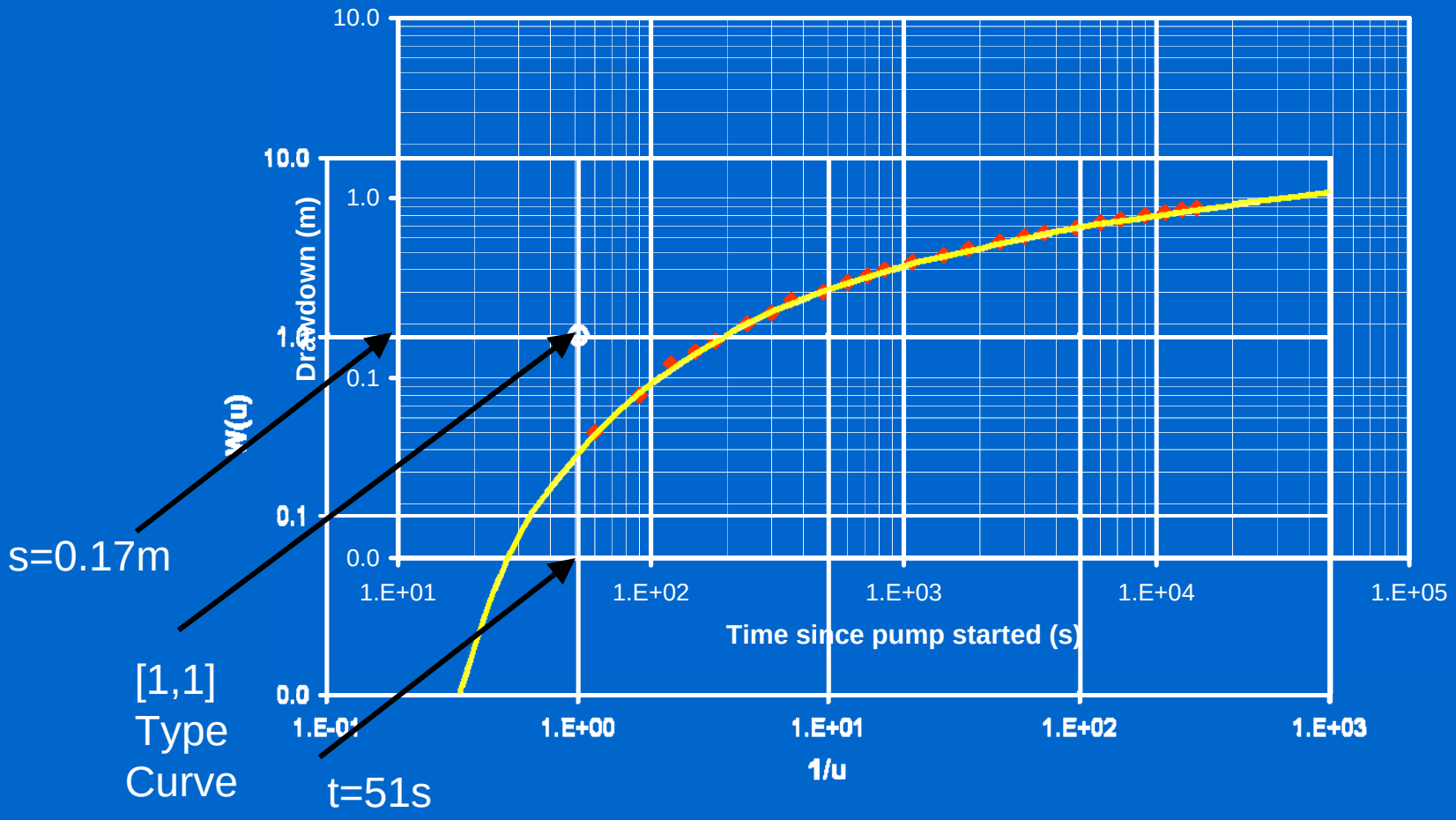
Theis Plot : 1/u vs W(u)



Theis Plot : Log(t) vs Log(s)



Theis Plot : Log(t) vs Log(s)



Theis Analysis

1. Overlay type-curve on data-curve keeping axes parallel
2. Select a point on the type-curve (any will do but [1,1] is simplest)
3. Read off the corresponding co-ordinates on the data-curve $[t_d,s_d]$
4. For [1,1] on the type curve corresponding to $[t_d,s_d]$, $T = Q/4\pi s_d$ and $S = 4Tt_d/r^2 = Qt_d/\pi r^2 s_d$
5. For the example, Q = 32 L/s or 0.032 m^3/s; r = 120 m; t_d = 51 s and s_d = 0.17 m
6. T = (0.032)/(12.56 x 0.17) = 0.015 m^2/s = 1300 m^2/d
7. S = (0.032 x 51)/(3.14 x 120 x 120 x 0.17) = 2.1×10^{-4}

Cooper-Jacob

- Cooper and Jacob (1946) pointed out that the series expansion of the exponential integral W(u) is:

 $$W(u) = -\gamma - \ln(u) + \frac{u}{1.1!} - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \ldots\ldots$$

 where γ is Euler's constant (0.5772)

- For $u << 1$, say $u < 0.05$ the series can be truncated:

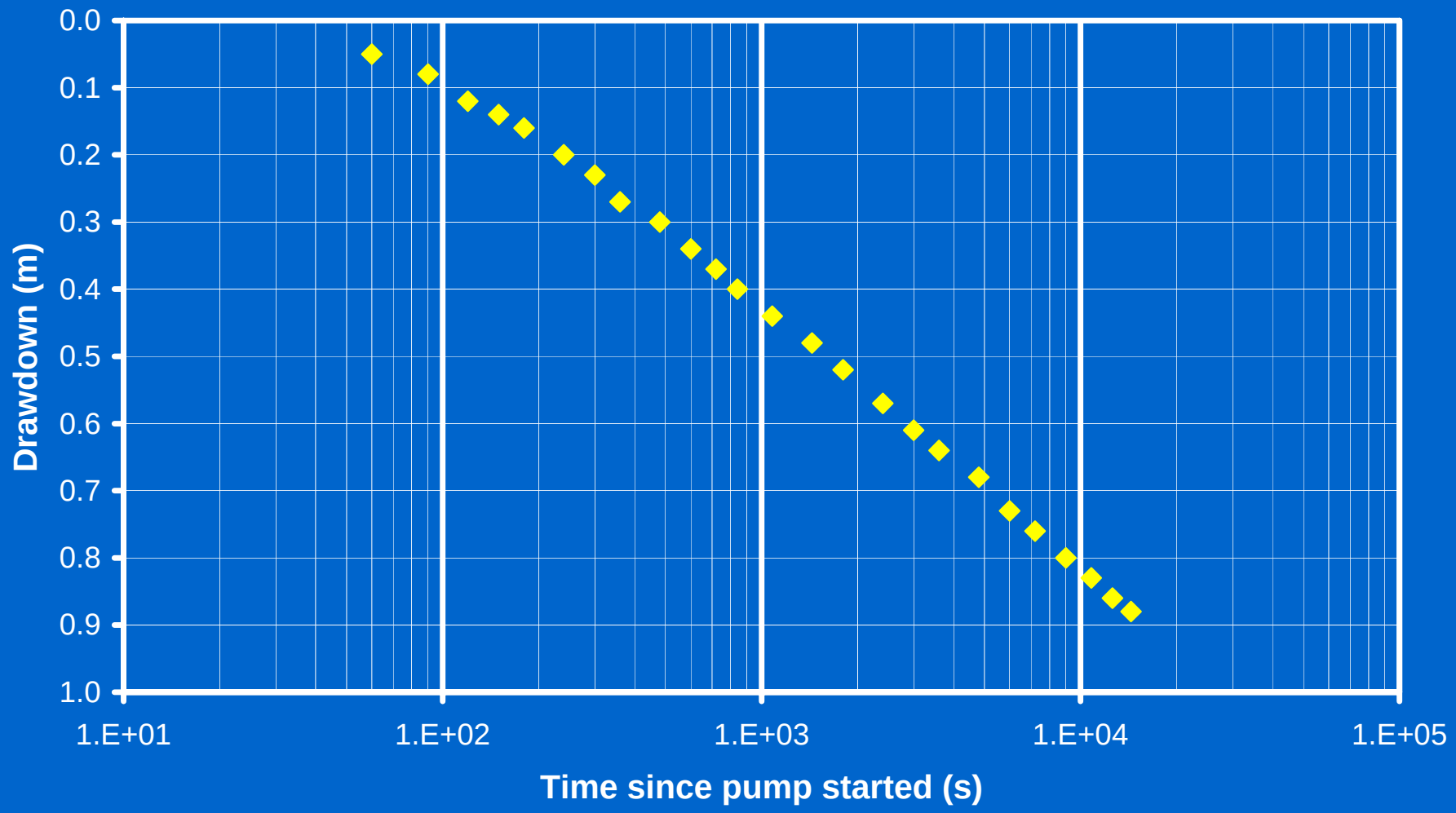
 $$W(u) \approx -\ln(e^{\gamma}) - \ln(u) = -\ln(e^{\gamma}u) = -\ln(1.78u)$$

- Thus: $$s = h_o - h = -\frac{Q}{4\pi T}\ln(1.78u) = -\frac{Q}{4\pi T}\ln\left(\frac{1.78r^2S}{4Tt}\right) = \frac{Q}{4\pi T}\ln\left(\frac{4Tt}{1.78r^2S}\right)$$

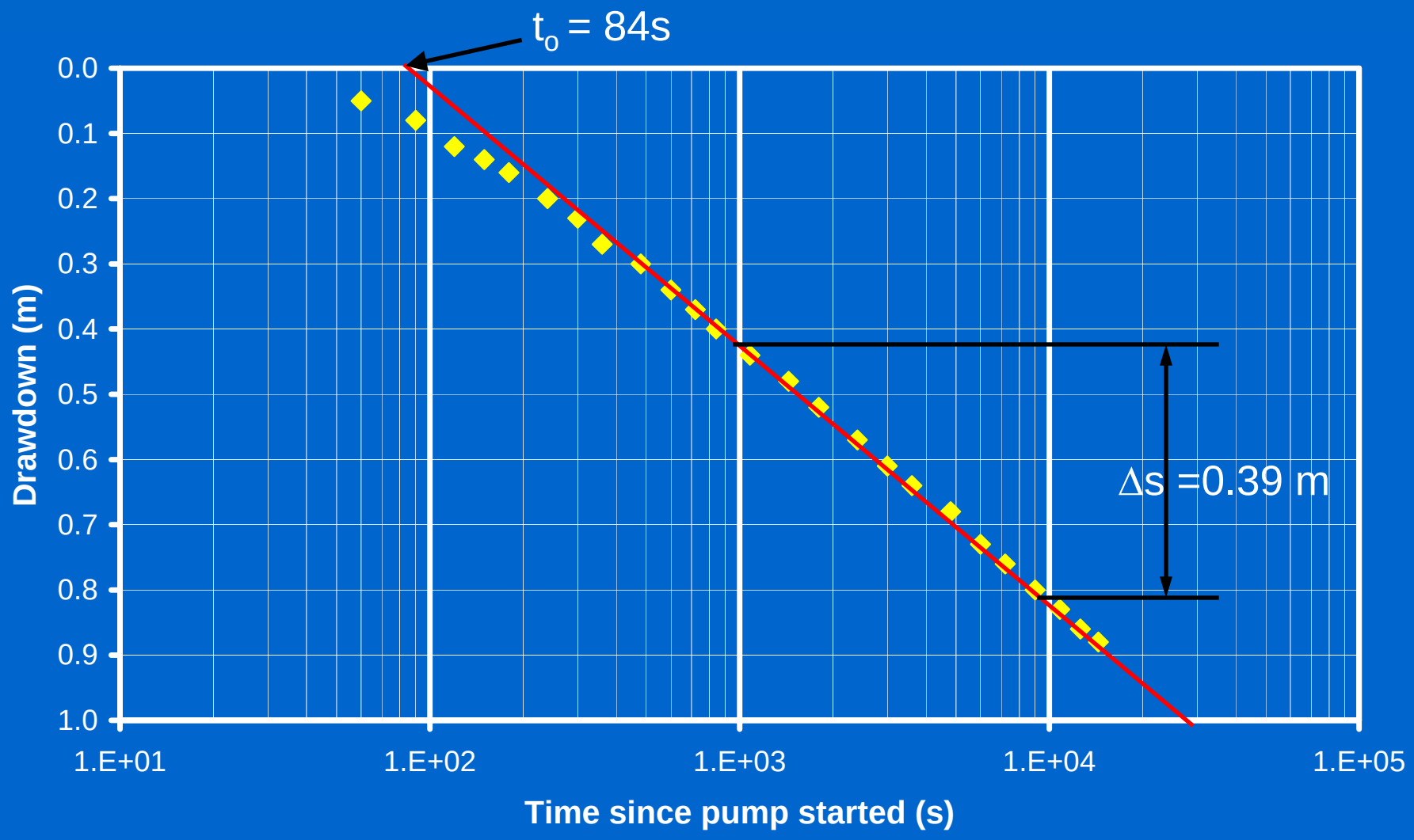
$$\boxed{s = h_o - h = \frac{Q}{4\pi T}\ln\left(\frac{2.25Tt}{r^2S}\right) = \frac{2.3\,Q}{4\pi T}\log\left(\frac{2.25Tt}{r^2S}\right)}$$

- The Cooper-Jacob simplification expresses drawdown (s) as a linear function of ln(t) or log(t).

Cooper-Jacob Plot : Log(t) vs s



Cooper-Jacob Plot : Log(t) vs s



Cooper-Jacob Analysis

1. Fit straight-line to data (excluding early and late times if necessary):
 - at early times the Cooper-Jacob approximation may not be valid
 - at late times boundaries may significantly influence drawdown
2. Determine intercept on the time axis for s=0
3. Determine drawdown increment (Δs) for one log-cycle
4. For straight-line fit, $T = 2.3Q/4\pi\Delta s$ and $S = 2.25Tt_o/r^2 = 2.3Qt_o/1.78\pi r^2\Delta s$
5. For the example, Q = 32 L/s or 0.032 m^3/s; r = 120 m; t_o = 84 s and Δs = 0.39 m
6. T = (2.3 x 0.032)/(12.56 x 0.39) = 0.015 m^2/s = 1300 m^2/d
7. S = (2.3 x 0.032 x 84)/(1.78 x 3.14 x 120 x 120 x 0.39) = 1.9 x 10^{-4}

Theis-Cooper-Jacob Assumptions

Real aquifers rarely conform to the assumptions made for Theis-Cooper-Jacob non-equilibrium analysis

- Isotropic, homogeneous, uniform thickness
- Fully penetrating well
- Laminar flow
- Flat potentiometric surface
- Infinite areal extent
- No recharge

The failure of some or all of these assumptions leads to “non-ideal” behaviour and deviations from the Theis and Cooper-Jacob analytical solutions for radial unsteady flow



- Other methods for determining aquifer parameters

 - Leaky - Hantush-Jacob (Walton)
 - Storage in Aquitard - Hantush
 - Unconfined, Isotropic - Theis with Jacob Correction
 - Unconfined, Anisotropic - Neuman, Boulton
 - Fracture Flow, Double Porosity - Warren Root
 - Large Diameter Wells with WellBore Storage - Papadopulos-Cooper

Pump Test Planning

- Pump tests will not produce satisfactory estimates of either aquifer properties or well performance unless the data collection system is carefully addressed in the design.
- Several preliminary estimates are needed to design a successful test:
 - Estimate the maximum drawdown at the pumped well
 - Estimate the maximum pumping rate
 - Evaluate the best method to measure the pumped volumes
 - Plan discharge of pumped volumes distant from the well
 - Estimate drawdowns at observation wells
 - Measure all initial heads several times to ensure that steady-conditions prevail
 - Survey elevations of all well measurement reference points

Number of Observation Wells

- Number of observation wells depends on test objectives and available resources for test program.
 - Single well can give aquifer characteristics (T and S). Reliability of estimates increases with additional observation points.

Pump Test Measurements

- The accuracy of drawdown data and the results of subsequent analysis depends on:
 - maintaining a constant pumping rate
 - measuring drawdown at several (>2) observation wells at different radial distances
 - taking drawdowns at appropriate time intervals at least every min (1-15 mins); (every 5 mins) 15-60 mins; (every 30 mins) 1-5 hrs; (every 60 mins) 5-12 hrs; (every 8 hrs) >12 hrs
 - measuring both pumping and recovery data
 - continuing tests for no less than 24 hours for a confined aquifers and 72 hours for unconfined aquifers in constant rate tests

AquiferTest Software

- AquiferTest is a quick and easy-to-use software program, specifically designed for graphical analysis and reporting of pumping test data.

These include:

- Confined aquifers
- Unconfined aquifers
- Leaky aquifers
- Fractured rock aquifers

Pumping Test Analysis Methods

- Theis (confined)
- Theis with Jacob Correction (unconfined)
- Neuman (unconfined)
- Boulton (unconfined)
- Hantush-Jacob (Walton) (Leaky)
- Hantush (Leaky, with storage in aquitard)
- Warren-Root (Dual Porosity, Fractured Flow)
- Moench (Fractured flow, with skin)
- Cooper Papadopulos (Well bore storage)
- Agarwal Recovery (recovery analysis)
- Theis Recovery (confined)
- Cooper Jacob 1: Time Drawdown (confined)
- Cooper Jacob 2: Distance Drawdown (confined)
- Cooper Jacob 3: Time Distance Drawdown (confined)

Graphical User Interface

The AquiferTest graphical user interface has six main tabs:

1. Pumping Test

The pumping test tab is the starting point for entering your project info, selecting standard units, managing pumping test information, aquifer properties, and creating/editing wells.

CPK-Test - AquiferTest

File Edit View Test Analysis Tools Help

Tests

Pumping Test

- Wells
 - Well 1
 - Well 2
- Discharge rates
 - Well 1
- Water level measurements
 - Well 2
 - Well 1
- Analyses
 - Theis Method
 - Cooper and Jacob
 - Create a New Analysis
 - Define analysis time range...
 - Add comments...
- Additional tasks
 - Import Wells from file...
 - Create a Pumping Test
 - Create a Slug Test
 - Contact Technical Support...

Pumping Test | Discharge | Water Levels | Analysis | Site Plan | Reports

Project Information

Project Name	Training Course
Project No.	AquiferTest Tutorial
Client	Govt. of West Bengal
Location	Kolkata

Units

Site Plan	m	Dimensions	m
Time	min	Discharge	m³/d
Transmissivity	m²/d	Pressure	Pa

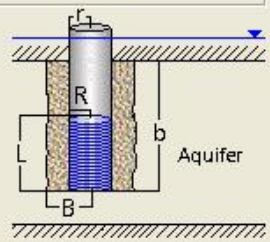
Convert existing values

Pumping Test

Name	Pumping Test
Performed by	NIH
Date	10/ 7/2009

Aquifer Properties

Thickness [m]	5
Type	Confined
Bar. Eff. (BE)	



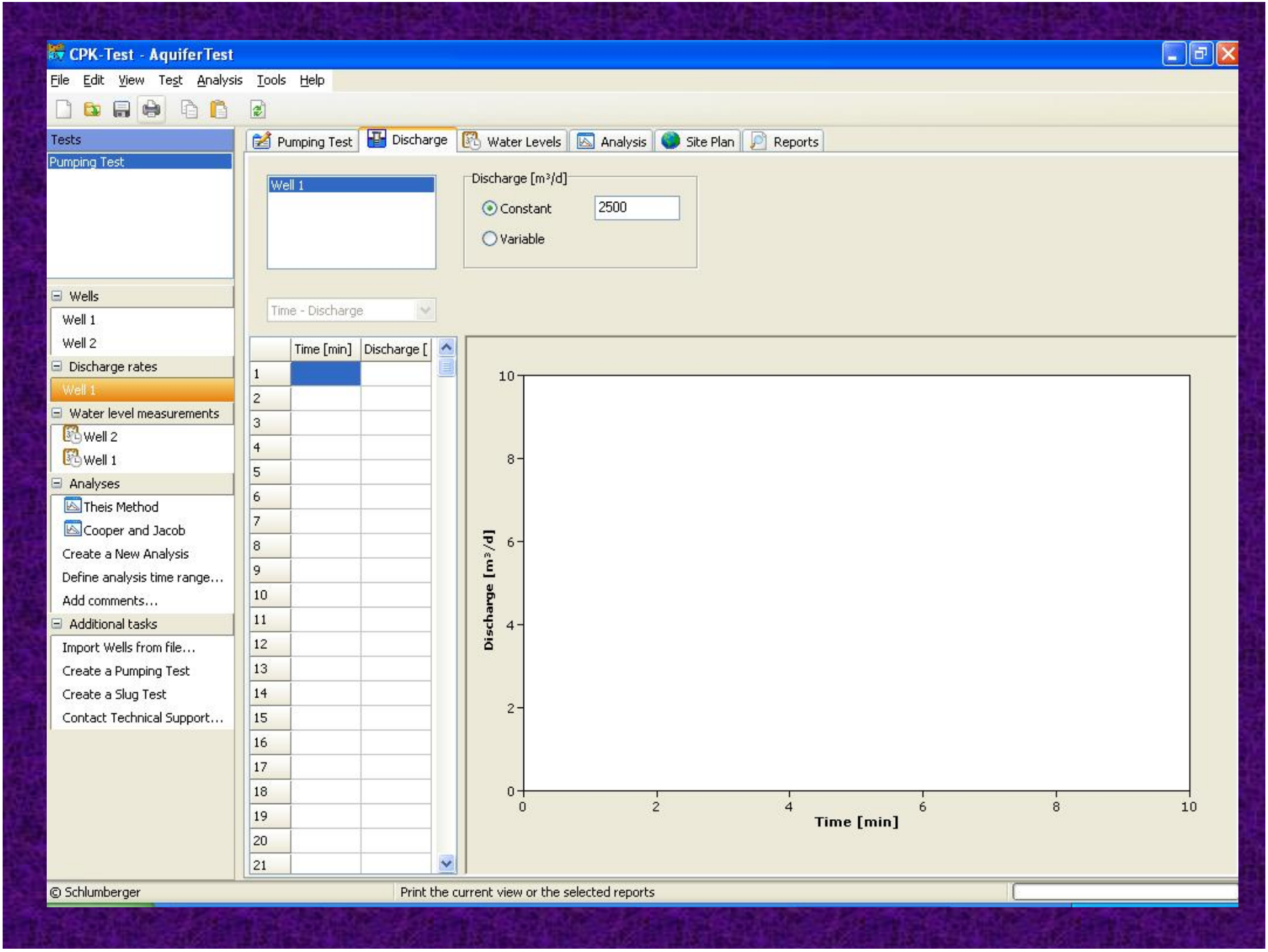
	Name	Type	X [m]	Y [m]	Elevation (al	Benchmark [	Penetration	R [m]	L [m]	b [m]	r [m]	B [m]
1	Well 1	Pumping Well	0	0	0	0	Fully	0.05	3		0.025	
2	Well 2	Observation Well	60	0	0	0	Fully	0.05	3		0.025	

Click here to create a new well

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2. Discharge

The Discharge tab is used to enter your constant or variable discharge data for one or more pumping wells.


CPK-Test - AquiferTest
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Pumping Test
Discharge
Water Levels
Analysis
Site Plan
Reports
Well 1
Discharge [m³/d]
Constant
2500
Variable
Time - Discharge
Time [min]
Discharge [
Discharge [m³/d]
Time [min]
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Print the current view or the selected reports

3. Water Levels

The Water Levels tab is where your time/drawdown data from observation wells is entered. Add barometric or trend correction factors to compensate for known variations in barometric pressure or water levels in your pumping or observation wells.

CPK-Test - AquiferTest

File Edit View Test Analysis Tools Help

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- Well 1

Water level measurements
- Well 2
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- Create a New Analysis
- Define analysis time range...
- Add comments...

Additional tasks
- Import Wells from file...
- Create a Pumping Test
- Create a Slug Test
- Contact Technical Support...

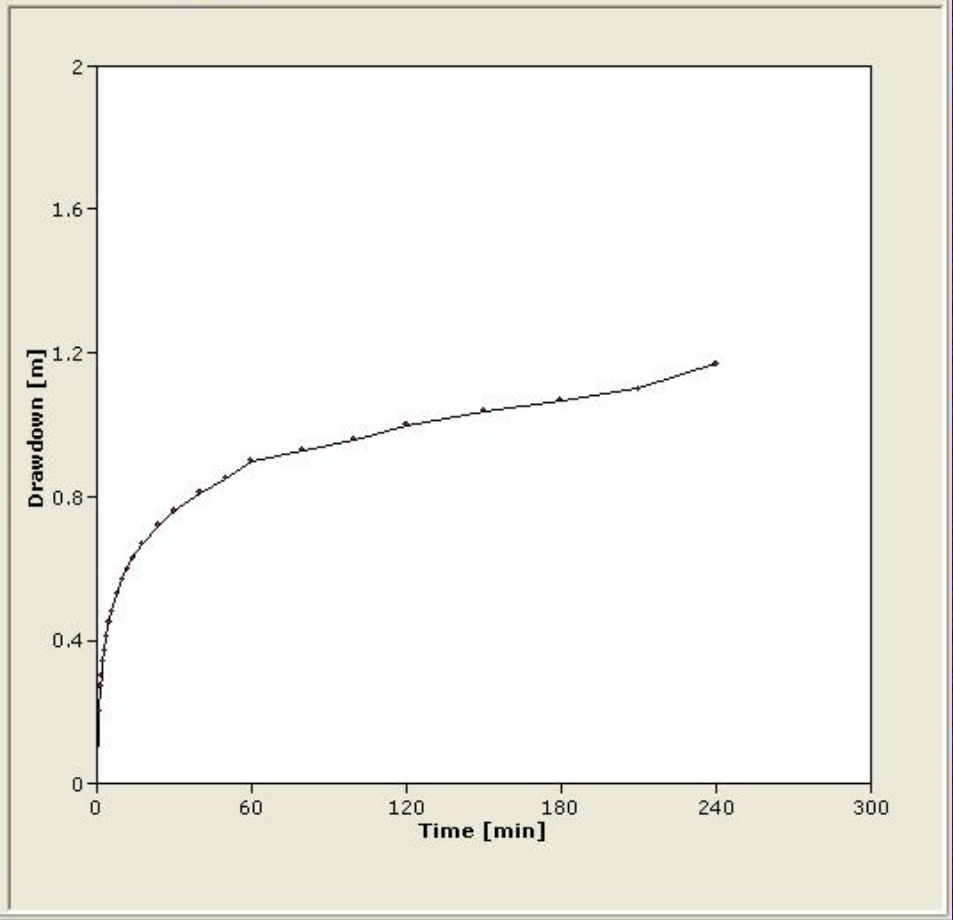
Pumping Test | Discharge | Water Levels | Analysis | Site Plan | Reports

Well 2
Well 1 (Pumping Well)

Static WL [m] 0

Import... | Time - Drawdown | Add Data Correction... | Filter

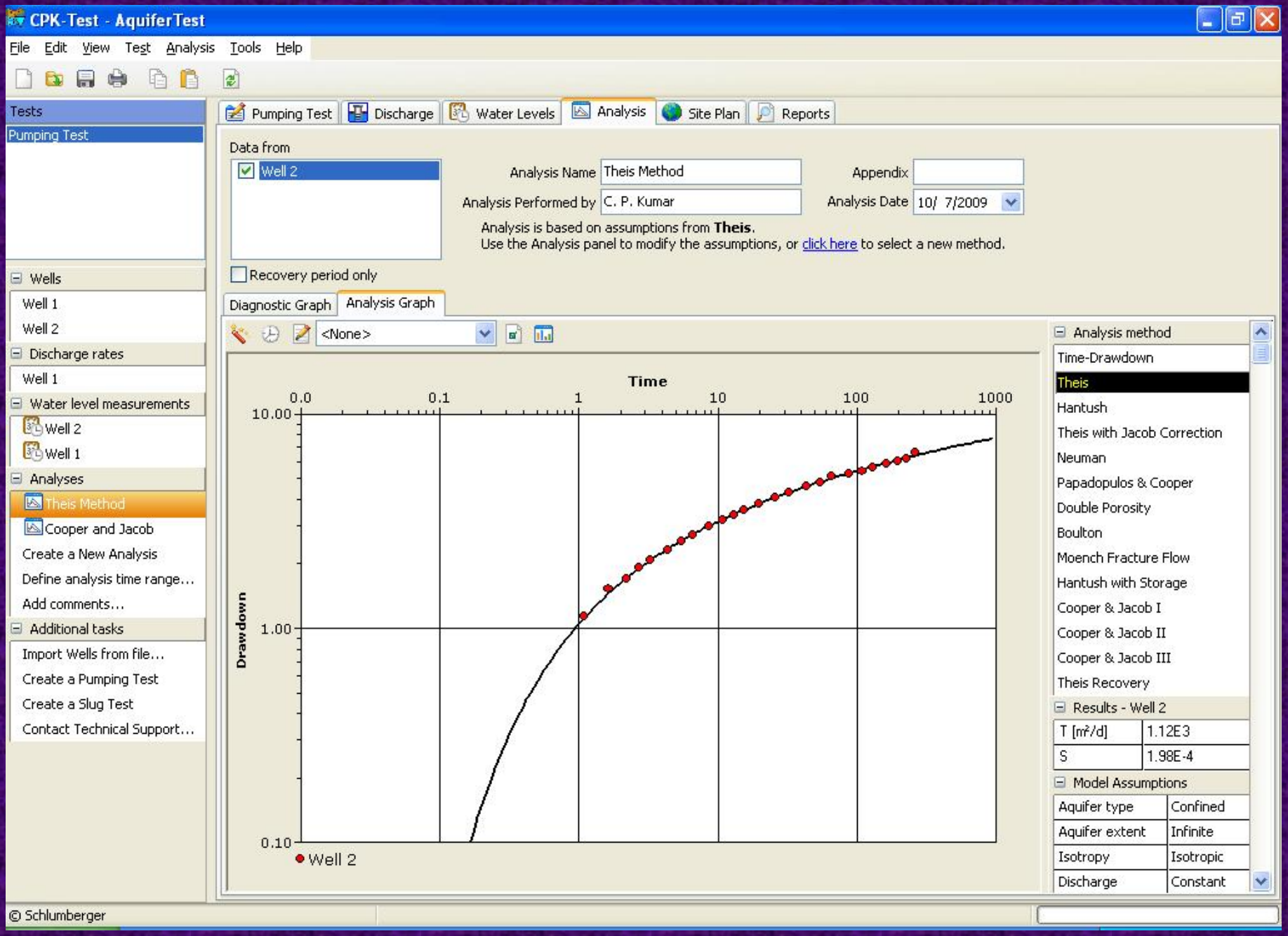
	Time [min]	Drawdown [m]
1	0	0
2	1	0.2
3	1.5	0.27
4	2	0.3
5	2.5	0.34
6	3	0.37
7	4	0.41
8	5	0.45
9	6	0.48
10	8	0.53
11	10	0.57
12	12	0.6
13	14	0.63
14	18	0.67
15	24	0.72
16	30	0.76
17	40	0.81
18	50	0.85
19	60	0.9
20	80	0.93
21	100	0.96
22	120	1
23	150	1.04



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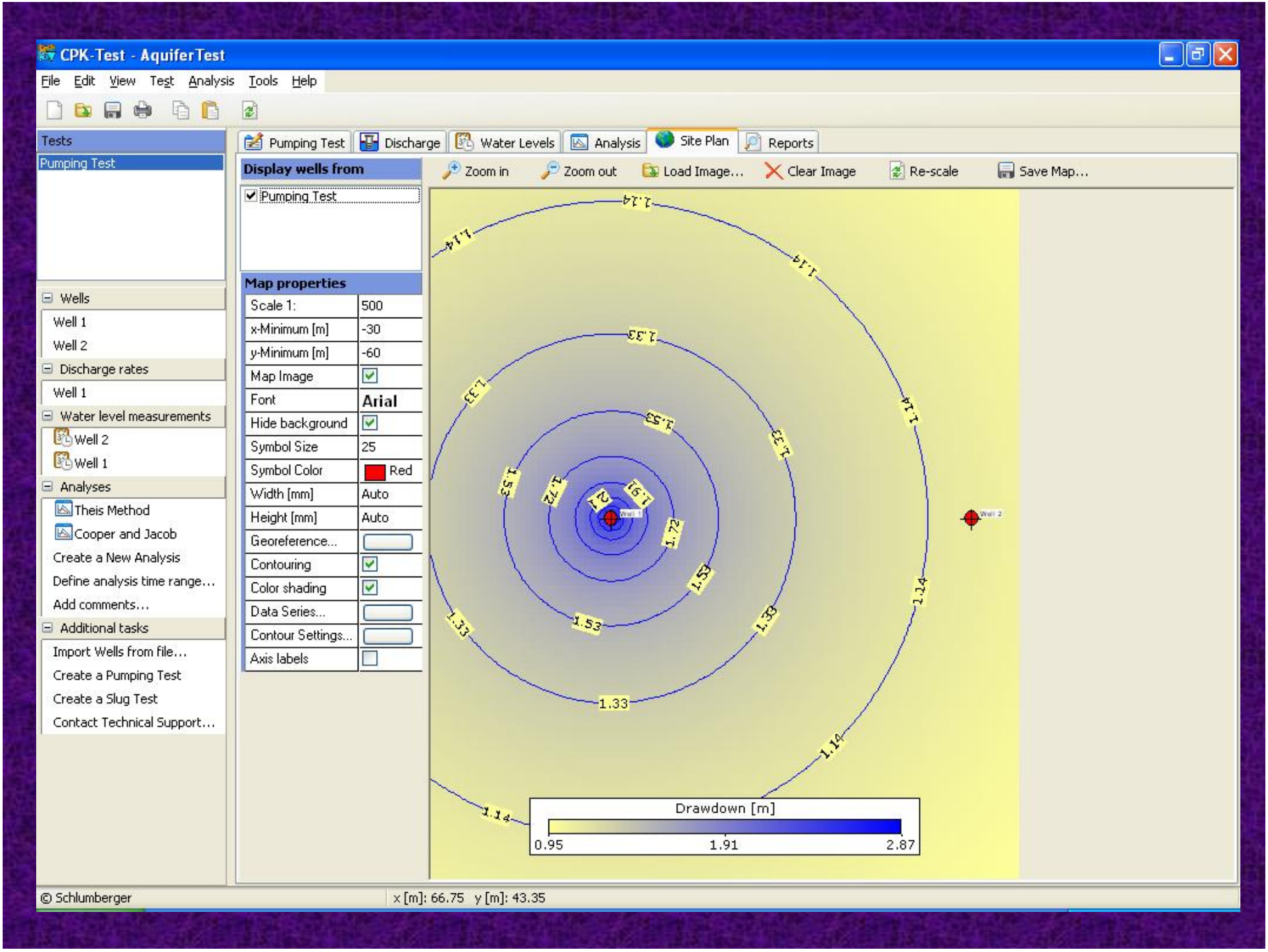
4. Analysis

The Analysis tab is used to display diagnostic and type curve analysis graphs from your data. View drawdown derivative data values and derivatives of type curves on analysis graphs for manual or automatic curve fitting and parameter calculations.


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Water Levels
Analysis
Site Plan
Reports
Data from
Well 2
Analysis Name
Theis Method
Appendix
Analysis Performed by
C. P. Kumar
Analysis Date
10/ 7/2009
Analysis is based on assumptions from Theis.
Use the Analysis panel to modify the assumptions, or click here to select a new method.
Recovery period only
Diagnostic Graph
Analysis Graph
<None>
Time
0.0
0.1
1
10
100
1000
10.00
1.00
0.10
Drawdown
Well 2
Analysis method
Time-Drawdown
Theis
Hantush
Theis with Jacob Correction
Neuman
Papadopulos & Cooper
Double Porosity
Boulton
Moench Fracture Flow
Hantush with Storage
Cooper & Jacob I
Cooper & Jacob II
Cooper & Jacob III
Theis Recovery
Results - Well 2
T [m²/d] 1.12E3
S 1.98E-4
Model Assumptions
Aquifer type Confined
Aquifer extent Infinite
Isotropy Isotropic
Discharge Constant
© Schlumberger

5. Site Plans

Use the Site Plan tab to graphically display your drawdown contours with dramatic colour shading over top of site maps.


CPK-Test - AquiferTest
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Pumping Test
Map properties
Scale 1: 500
x-Minimum [m] -30
y-Minimum [m] -60
Map Image
Font Arial
Hide background
Symbol Size 25
Symbol Color Red
Width [mm] Auto
Height [mm] Auto
Georeference...
Contouring
Color shading
Data Series...
Contour Settings...
Axis labels
Zoom in
Zoom out
Load Image...
Clear Image
Re-scale
Save Map...
Drawdown [m]
0.95
1.91
2.87
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x [m]: 66.75 y [m]: 43.35

6. Reports

Use the Report tab to create professional looking output using a number of pre-defined report templates.

CPK-Test - AquiferTest

File Edit View Test Analysis Tools Help

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- Well 2

Discharge rates
- Well 1

Water level measurements
- Well 2
- Well 1

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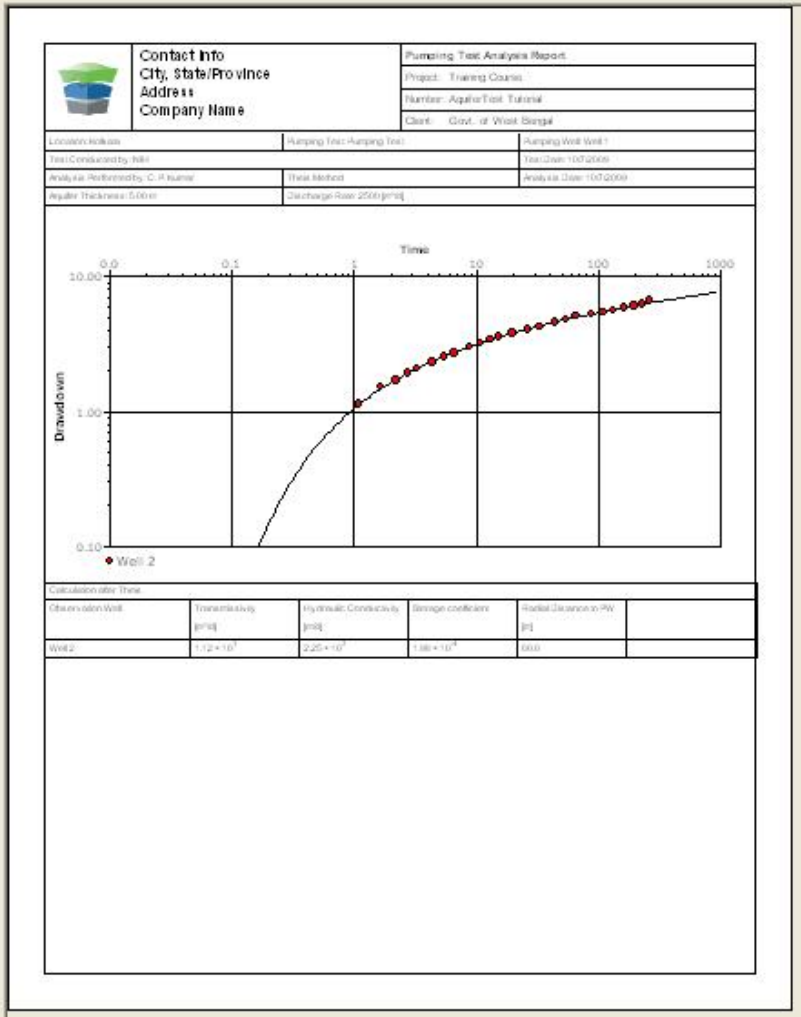
Additional tasks
- Import Wells from file...
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- Create a Slug Test
- Contact Technical Support...

Pumping Test | Discharge | Water Levels | Analysis | Site Plan | Reports

Select Printouts

- Site Map
- Wells
- Water Level Data
 - Well 2
- Analysis Graphs
 - Theis Method
 - Cooper and Jacob
- Analysis Table

Print preview: Page | Previous page | Next page | Layout...



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Tutorial Problem

A well penetrating a confined aquifer is pumped at a uniform rate of 2500 m^3/day. Drawdowns during the pumping period are measured in an observation well 60 m away; Observation of time and drawdown are listed in the Table.

Determine the transmissivity and storativity by Theis method and Cooper-Jacob method using the AquiferTest software.

Table: Pumping Test Data

Time (min)	**Drawdown** (m)
0	0
1.0	0.20
1.5	0.27
2.0	0.30
2.5	0.34
3.0	0.37
4	0.41
5	0.45
6	0.48
8	0.53
10	0.57
12	0.60
14	0.63
18	0.67
24	0.72
30	0.76
40	0.81
50	0.85
60	0.90
80	0.93
100	0.96
120	1.00
150	1.04
180	1.07
210	1.10
240	1.17



Answer -

(i) $T = 1110\ m^2/day$,
$S = 0.000206$

(ii) $T = 1090\ m^2/day$,
$S = 0.000184$


Thank You !!!